# In Search of Internationalized Operator Interface Displays in Process Control: A Comparison among Malaysian, Singaporean and Chinese

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**Abstract**. Developing culturally neutral products may not only reduce the cost of production but also enhance the share in current emerging international market. In this study, 266 Malaysian operators from various industrial sites in Malaysia were recruited to answer a computerized questionnaire regarding their perceptions of colors, shapes and orientations commonly found on the operator interface displays for Distributed Control System (DCS). The analyzed data was compared with the previous findings from Singapore and China. There exists great consistency in the perceptions of these three different culture groups. On the basis of cultural similarities found in the three studies, we elicit general design guidelines that may be applied in internationalizing operator interface displays.

*Keywords.* Visual perception, Internationalization, Operator interface, Process control.

## 1. Introduction

The interaction between the operator and the Distributed Control System (DCS) usually can be categorized into three layers listed below (Liang and Plocher, 2003):

*Display Codes*: Symbols used to display information, such as languages, texts, formats, layout orientations, colors, shapes, graphics, sounds and voices

*Information Architecture*: the style and manner used to construct and access the information, such as information labeling, navigation, organization and search

*User Interaction*: the style and manner used to exchange information, such as error messages, helps and aids.

In this study, we focused on the use of *Display Codes* for the design of operator interface displays with special emphasis on the issue of internationalization.

While it is not difficult to find the relevant information for the design of operator interface displays from handbooks, industry standards or guidelines (Moray, 1997), it is also not surprising to find many inconsistencies in the information with respect to the use of colors, shapes and layout orientations (Honeywell, 2002). Hence, there are no universal standards or guidelines for the design of operator interface displays. It is also not appropriate to simply apply the relevant industry standards, such as the ISO 3864 and ANSI Z535 series, to the design of operator interfaces (Honeywell, 2002) for the purpose of internationalization

One limitation on the use of display codes is that the operator must remember the meaning of the codes (Brauer, 1994). The interpretations of the codes by operators are influenced by their work experiences as well as their cultural background. That is, they tend to decipher the codes based on what they learned. Although there are several sources of reference on the design of display codes for internationalization (e.g., Dreyfuss, 1984; Fernandes, 1995; Miller et al., 2000; Peterson and Cullen, 2000), the suggestions are typically more artistic from the perspectives of design and marketing, rather than empirical and data-driven. Clearly, most Western operators are more accustomed to certain display codes commonly found on the operator interface displays for the DCS products, but the question is: how well do these codes get recognized and accepted by similar operators in the Asia Pacific region? Also, are there common grounds in code perception between different culture groups in Asia? Few efforts have been made in Hong Kong (Luximon et al., 1998), Singapore (Liang et al., 2000) and China (Honeywell, 2000) to investigate user interface designs related to the use of display codes in operator interfaces.

Therefore, the primary objective of the study reported in this paper was: (1) to extend the previous research findings to operators in Malaysia, through evaluating their perceptions of colors, shapes and layout orientations, and then (2) to compare the results from three user populations in Malaysia, Singapore and China with the aim to suggest the use of relevant display codes for internationalization, thereby improving the usability of operator interface displays in process control. The assumption was that there could be greater similarities than differences between the Asian culture groups.

## 2. Methodology

This field survey was specially designed to use a computerized questionnaire. That is, participants' responses were directly logged on to a computer, and they could not back track or

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change their responses once they have answered each question. The study sample comprised mainly of volunteers, derived from various industrial sites in Malaysia, pertaining to the petrochemical, gas and natural oils industry. The survey was conducted on-site at the operators' workplaces. Subjects were instructed to answer all questions on the computer screen by clicking a mouse. The questionnaire contained ratings on the associations between the degree of temperature and colors, and between hazard level and colors. Subjects were also asked to associate a shape with a given process control term. In addition, the layout orientation was tested where subjects were asked to click on the boxes with different layouts in their desired sequence. The completion time for the questionnaire was about 15 minutes. Subjects' responses were logged directly into a database. This testing approach helped to expedite the collection of data and transfer to other languages. There were two language versions used in this study, namely Malay (*Bahasa Melayu*) or English as preferred by the operators.

*2.1. Color association questions*

There were eighteen questions on the associations between colors and degree of temperature, and between colors and hazard level. Temperature was rated at 5 levels from Cold, Cool, Not cool, Not warm, Warm, to Hot. Hazard too had 5 levels: from Very safe, Safe, Neutral, Dangerous to Very Dangerous. A total nine colors were selected for the study, namely: Red, Orange, Gray, Yellow, Green, Blue, Purple, White and Black. The colors were displayed one at a time on the top center of the computer screen. Subjects indicated their choices by clicking on one of the five option buttons shown on the screen. They then clicked the "done" button at the right-bottom corner of the screen to proceed to the next question. The nine colors were randomly assigned into the display sequence for each subject to eliminate the effects of order. Figure 1 presents the screen layout for the color association questions on temperature.

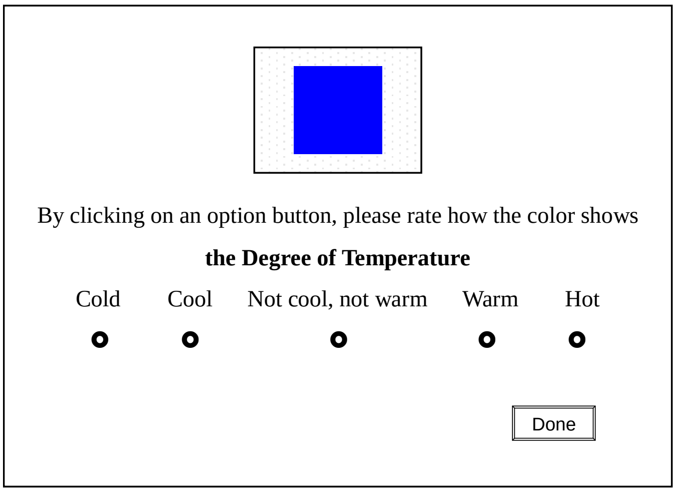


Figure 1. Color Association Question: The Degree of Temperature

*2.2. Shape association questions*

Four questions were asked regarding the associations between shapes and four general terms commonly used in industrial process control, that is, Normal, Caution, Stop, and Alarm. For each process control term, subjects indicated their choices by clicking on one of the twelve shapes (Circle, Oval, Square, Rounded Square, Rectangle, Rounded Rectangle, Triangle, Diamond, Octagon, Plaque, Trapezoid and Star) shown on the computer screen to indicate the best association between the selected shape and the term shown on the screen. Likewise before, they then clicked on the "done" button to move on to the next question. Figure 2 presents the screen layout of the shape association question for the term 'Normal'.

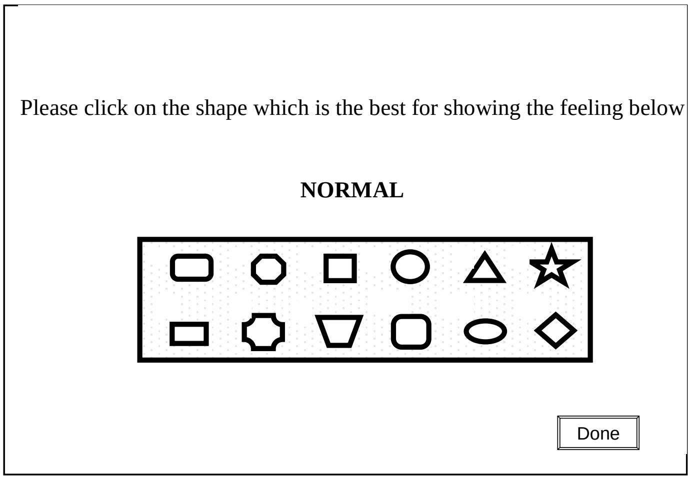


Figure 2. Shape Association Question: Normal

*2.3. Layout orientation questions*

Four questions were asked with respect to the perception of the layout orientation. Four different layouts, composed of four identical boxes were used to test subjects' layout orientations. Subjects were asked to click on the boxes in a sequence they so desired. These four layouts were the Vertical Line, the Horizontal Line, the Diamond and the Square. Again, subjects clicked on the "done" button to move to the next question. Figure 3 presents the screen layout of the layout orientation question for the Vertical Line layout.

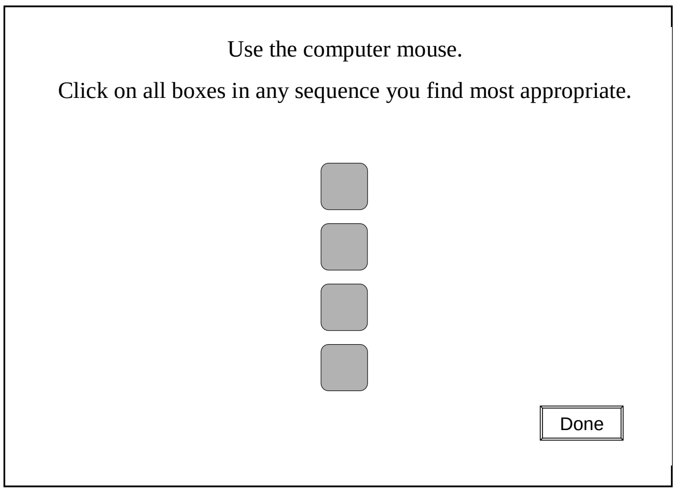


Figure 3. Layout Orientation Question: Vertical Line

## 3. Results and Discussion

*3.1. Subject demographics*

The sample (N=266) comprised predominantly male operators (n=265) and a female. This is not surprising given the nature of the industry. Subjects were aged between 19 to 54 years with a mean age of 32.3 years, and standard deviation of 7.3 years old. The subjects were recruited from both East Malaysia (n=151) and West Malaysia (n=115). Subjects were given the language option, and 135 answered the questionnaire in Malay, while 131 in English. The ethnic components of the sample reflected the diversity of the Malaysian population. Malays composed about 45% of the subjects, 16% were Chinese, 6% were Indian, and indigenous peoples (e.g., Iban, Bidayuh and Melanau) and other ethnic groups made up the rest of 33%. About 99% of the subjects' current nationality and nationality at birth was Malaysian. About 81% of the subjects had formal education between 11 to 15 years, 8% were 10 years or less, and 11% were 16 years or over. In terms of work experience in industry, about 22% had 3 years or less, 19% were between 4 to 7 years, 25% were between 8 to 11 years, 8% were between 12 to 15 years, and 26% were 16 years or over.

*3.2. Color association*

The five levels of temperature and the five levels of hazard were coded from high to low, using five digits that ranged from 5 to 1, respectively. The means and standard deviations of these nine colors for the associations with the degree of temperature and the hazard level are presented in Table 1.

Table 1. Means and standard deviations of the nine colors

| | Temperature | | Hazard Level | |
|---|---|---|---|---|
| | Mean | S. D. | Mean | S. D. |
| Red | 4.8 | 0.6 | 4.6 | 0.6 |
| Orange | 4.1 | 0.8 | 3.9 | 0.7 |
| Yellow | 3.3 | 1.0 | 3.0 | 0.9 |
| Purple | 3.0 | 1.0 | 3.0 | 0.7 |
| Black | 2.9 | 1.4 | 3.6 | 1.0 |
| Gray | 2.7 | 1.1 | 3.1 | 0.9 |
| Green | 2.4 | 1.0 | 2.0 | 0.9 |
| Blue | 2.2 | 0.9 | 2.3 | 0.8 |
| White | 2.1 | 1.1 | 2.1 | 0.9 |

Due to the nature of an ordinal scale, the Wilcoxon Singed-Rank tests were used to test the order of color ratings. The results are shown in Figure 4.

← Higher Temperature Lower →

Red Orange Yellow <u>Purple Black</u> Gray Green <u>Blue White</u>

← Higher Hazard Level Lower →

Red Orange Black <u>Gray Yellow Purple</u> Blue <u>White Green</u>

An underline indicates that the means are not significantly different at $p < 0.05$

Figure 4. Color Associations with the Degree of Temperature and the Hazard Level

For the color association with the degree of temperature, red represented the highest temperature, followed by orange. Yellow was next in the middle range, followed by purple and black without any significant difference between each other. The last in this range was gray. Green represented the lower temperature, whereas both blue and white could represent the lowest temperature.

For the color association with the hazard level, red represented the highest hazard level, followed by orange, then black. Gray, yellow and purple were in the middle without significant differences among them. While blue represented the lower hazard level, both white and green could represent the lowest hazard level.

It was clear from the results that red was the only color which associated both with the highest temperature and hazard level, while white associated both with the lowest temperature and hazard level. A comparison of the means showed the color-temperature association had similar coding level to that of the hazard level, with the exception of black. The latter seemed to represent intermediate degree of temperature, but was also associated with higher (dangerous) hazard level.

*3.3. Shape association*

The percentages of the shape association with the four process control terms are presented in Table 2. Note that only the shapes with the top-three percentages for the terms are listed in the table.

Table 2. Percentages of the shape association with process control terms

| | Normal | Alarm | Stop | Caution |
|---|---|---|---|---|
| Octagon | 1% | 2% | **17%** | 6% |
| Square | **35%** | 2% | 6% | 3% |
| Circle | **28%** | 0% | 7% | 2% |
| Triangle | 2% | **34%** | **31%** | **45%** |
| Star | 3% | **40%** | 5% | **16%** |
| Diamond | 2% | **8%** | **15%** | **12%** |
| Oval | **12%** | 2% | 2% | 1% |
| Others | 17% | 12% | 17% | 15% |

Note: Top-three percentages for each term are in **bold**.

The results showed that the shape Square and Circle were the two popular shapes to represent the Normal condition with 35% and 28%, respectively, followed by the Oval with 12%. For the Alarm concept, the Star and Triangle were the choices with 40% and 34%, correspondingly, followed by the Diamond with 8%. The Triangle was the first choice to represent Stop with 31% agreement, followed by the Octagon with 17% and the Diamond with 15%. The term Caution was highly associated with the shape Triangle at 45% level, followed by the Star and Diamond with 16% and 12%, respectively.

Considering the representations of these four process control conditions, there was absolutely no ambiguity in representing the concept ‘Normal’ with the Square and Circle, or even the Oval, since these three shapes were clearly selected to relate to the Normal condition, but not the others. Similar situation was found for the Octagon to represent the Stop condition. For the Triangle, however, it was commonly selected to represent Alarm, Stop, and Caution. Similar results were found for the Star to represent Alarm and Caution conditions, and the Diamond to symbolize the conditions of Alarm, Stop and Caution.

*3.4. Layout orientation*

For the Vertical Line layout, 58% of the subjects preferred the sequence order from top to bottom, while 21% preferred the bottom-up sequence. This confirmed previous findings that the top-down sequence was much preferred in presenting display options (Khalid, 2003).

For the Horizontal Line layout, 73% preferred the left to right sequence than from right to left, with only 12% opting for this horizontal layout. This may be due to the cultural dominance of left-right orientation in the Malay culture which made up a significant proportion of the sample (46%), relative to Chinese (16%). The latter has a cultural tendency to read text from right-to-left and from top-to-bottom.

For the Diamond layout, the majority of the subjects (44%) clicked the boxes in the direction of clockwise starting from the top. The second popular sequence was also in the direction of clockwise starting from the left, with 10% opting for this option.

Finally, the preferred sequence for the Square layout was from left to right, starting from the top two boxes (34%), followed by the bottom boxes. The second popular sequence was from top to bottom starting from the left two boxes then the right boxes (22%). The third popular sequence was clockwise starting from the top left box (18%).

Comparing the percentages of the most popular sequences for the Diamond and Square layouts (i.e. 44% and 34%, respectively), the obtained higher percentages on the most selected sequences for Vertical Line (58%) and Horizontal Line (73%) layouts indicated that subjects had better agreement with the Line layouts than they did on either the Diamond or Square layouts.

## 4. Comparisons among Three Cultural Groups

*4.1. Background of sample*

In the previous studies (Liang et al., 2000; Luximon et al., 1998), the subjects comprised mainly university students. As such, the mean age of subjects in these past studies was lower, about 19 years, with age ranging from 17 to 22 years (Liang et al., 2000). Another difference was the subjects’ nature of work. The subjects in the Malaysian study were real process control operators, while those in the past studies were just students majoring in Chemical Engineering. However, it can be said that both sample groups had of the appropriate knowledge about process control. A third notable difference, there were more Chinese subjects in the Singapore and China sample than in the Malaysian study.

*4.2. Color association*

With respect to the color-temperature association, the results from the Singaporean sample (Liang et al., 2000) were consistent with the results of the Malaysian sample. Red represented the highest degree of temperature, followed by orange. White and blue both represented the lowest temperature. Chinese subjects also associated red with the highest degree of temperature, followed by orange then yellow (Honeywell, 2000). However, they preferred to use black to represent the lowest temperature, which differed from Singaporeans and Malaysians.

In terms of color association with hazard level, the results from these three different culture groups showed greater consistency: Red was the unanimous color to represent the highest hazard level, followed by orange, whereas white was the color to represent the lowest hazard level. However, Malaysian subjects associated black, but not yellow, to the higher hazard level. This was the converse for Chinese subjects who chose yellow. The Singaporean subjects chose both yellow and black to represent the same hazard level. The overall comparisons of color associations among the three cultural groups are shown in Table 3.

Table 3. Overall comparisons of color association

| | Chinese | Malaysian | Singaporean |
|---|---|---|---|
| Temperature<br><br>Higher<br>↕<br>Lower | [Red]<br>[Orange]<br>[Yellow]<br>↕<br>[Gray & Blue]<br>[Black] | [Red]<br>[Orange]<br>[Yellow]<br>↕<br>[Blue]<br>[White] | [Red]<br>[Orange]<br>↕<br>[White & Blue] |
| Hazard Level<br><br>Higher<br>↕<br>Lower | [Red]<br>[Orange]<br>[Yellow]<br>↕<br>[Blue, White & Green] | [Red]<br>[Orange]<br>[Black]<br>↕<br>[Blue]<br>[White & Green] | [Red]<br>[Orange]<br>↕<br>[Blue & Green]<br>[White] |

In sum, red and orange were consistently chosen to represent the higher degree of temperature and the higher hazard level for these three cultural groups, where as blue may depict the lower temperature but not necessarily the lowest for the groups. While blue, green and white would represent the lower hazard level, white seems to be the consensus color to represent the lowest.

*4.3. Shape association*

Likewise the findings from the Malaysian survey, a majority of the Singaporean subjects associated the shapes of circle and square with the Normal condition. The circle also had the highest percentage of association with the Chinese subjects.

For the association with the Alarm condition, the first two popular shapes for the Singaporean subjects were the Triangle and Star, while the Triangle was also the most favorite shape with the Chinese subjects to represent the Alarm. These findings were similar to that obtained with the Malaysian subjects.

The Octagon was the most preferred shape for Singaporean subjects to represent Stop, followed by the shape triangle. This choice was not supported by the Malaysian sample; they chose triangle to octagon. With the Chinese subjects, the most representative shape to be associated with Stop was the Triangle. The Octagon was not even in their list of preferred shapes.

Both Malaysian and Singaporean subjects preferred to use the Triangle to represent Caution, followed by the shape Diamond. The Chinese subjects' preference was not clear. All four shapes (Triangle, Diamond, Star and Trapezoid) had the same percentage.

In general, Circle may be the preferred shape to represent a Normal condition for these three cultural groups. Triangle could be used to represent Alarm, Stop and Caution. However, to distinguish further among the three conditions, there is a need to have more display coding dimensions.

*4.4. Layout orientation*

Comparatively, there were similar results for the Vertical and Horizontal Line layouts, between the Malaysian survey and past studies. The dominant sequence appeared to be from top to bottom and from left to right, respectively, for both Singaporean and Chinese subjects. The percentages of these sequences for the Singaporean and Chinese subjects were even higher than the percentages for the Malaysian subjects. While this finding may be a little surprising given that the subjects are predominantly from the Chinese ethnic group, with a strong top-down sequence in text-reading, but the left-right sequence suggests the influence of an English orientation in reading text. This could be true for Singapore, and perhaps Hong Kong where the Chinese sample was derived.

For the Diamond layout, a majority of the Singaporean and Chinese subjects chose the clockwise direction starting from the top, just as found in the Malaysian study.

Finally, for the Square layout, the preferred sequence for all three cultural groups was from left to right, starting from the top to the bottom.

In short, it can be concluded that the most favorite sequence for each layout was the same among the three cultural groups. Also, all the subjects had more agreement on the Line layouts than they did on either the Diamond or the Square layouts.

## 5. Greatest Common Design Guidelines

Similar to the mathematical concept of the Greatest Common Divisor (GCD), the findings from these studies may be used to derive the "Greatest" Common Design Guidelines (GCDGs) for the Malaysian (M), Singaporean (S) and Chinese (C) user population as listed below. These guidelines, however, are purely generated from the results of this study. To be useful for the design of internationalized operator interface displays, some general design guidelines for visual displays have to be considered as well.

*5.1. Colors*

*5.1.1. Association with the degree of temperature*

GCDG01(M, S, C): Red is suitable to represent the highest degree of temperature.

GCDG02(M, S, C): Orange is suitable to represent the higher degree of temperature but not the highest.

GCDG03(M, S, C): Blue is suitable to represent the lower degree of temperature but might not the lowest.

GCDG04(M, C): Yellow is suitable to represent the higher degree of temperature but not the highest.

GCDG05(M, S): White is suitable to represent the lowest degree of temperature.

*5.1.2. Association with the hazard level*

GCDG06(M, S, C): Red is suitable to represent the highest hazard level.

GCDG07(M, S, C): Orange is suitable to represent the higher hazard level but not the highest.

GCDG08(M, S, C): White is suitable to represent the lowest hazard level.

GCDG09(M, S, C): Blue is suitable to represent the lower hazard level but might not the lowest.

GCDG10(M, S, C): Green is suitable to represent the lower hazard level but might not the lowest.

GCDG11(M, S): Blue is suitable to represent the lower hazard level but not the lowest.

*5.2. Shapes*

*5.2.1. Association with the normal condition*

GCDG12(M, S, C): Circle is suitable to represent the normal condition.

GCDG13(M, S): Square is suitable to represent the normal condition.

*5.2.2. Association with the alarm condition*

GCDG14(M, S, C): Triangle is suitable to represent the alarm condition.

GCDG15(M, S): Star is suitable to represent the alarm condition.

*5.2.3. Association with the stop condition*

GCDG16(M, S, C): Triangle is suitable to represent the stop condition.

GCDG17(M, S): Octagon is suitable to represent the stop condition.

*5.2.4. Association with the caution condition*

GCDG18(M, S, C): Triangle is suitable to represent the caution condition.

GCDG19(M, S, C): Diamond is suitable to represent the caution condition but not as suitable as Triangle.

GCDG20(M, C): Star is suitable to represent the caution condition but not as suitable as Triangle.

### *5.3. Layout orientations*

#### *5.3.1. Vertical line layout*

GCDG21(M, S, C): The stereotypical sequence is from top to bottom.

#### *5.3.2. Horizontal line layout*

GCDG22(M, S, C): The stereotypical sequence is from left to right.

#### *5.3.3. Diamond layout*

GCDG23(M, S, C): The stereotypical sequence is clockwise starting from the top.

#### *5.3.4. Square layout*

GCDG24(M, S, C): The stereotypical sequence is from left to right starting from the top two boxes then the bottom boxes.

## 6. Conclusion

The results from the Malaysian and past studies on Singaporean and Chinese sample provide useful information that may be used in the design of internationalized operator interface displays, particularly with respect to people's perception of colors, shapes and layout orientations. The similarities among the three cultural groups confirmed our assumption, and this "greatest common divisor" among different culture groups is regarded as the first step in internationalization.

We have proposed the Greatest Common Design Guidelines (GCDGs) as an attempt to support internationalized operator interface displays in process control. These guidelines have to be used together with other general design guidelines or standards that are available from the literature. Although several guidelines have indicated that color is not an effective factor for representing equipment conditions, eliminating the use of color totally or merely using color as a redundant code for such coding purposes need to be reviewed in light of our findings. The orientation stereotypes have a role to play in understanding arrangement of important blocks of information on a screen for optimal effectiveness. In addition, we also need to consider the compatible mappings between the displays and the controls.

In this Malaysian study, the dimensions of display codes have been studied individually (i.e., color, shape and layout orientation). It is also important to study the various combinations of these display code dimensions, such as the combination of colors and shapes. Future research could also investigate on the stereotypes and preferences of colors, shapes and layout orientations in different cultural groupings, such as the Japanese, Koreans, Thais and Indonesians. It would be interesting if there exist similarities that could characterize the Asian user population generically.

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